An upper limit on the X-ray luminosity of the black hole - microlens OGLE-1999-BUL-32

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We present an upper limit on the 3–20 keV X-ray flux from the black hole - microlens OGLE-1999-BUL-32 , based on RXTE/PCA scans over the Galactic Center region in 1999-2000. It is shown that the X-ray luminosity of the black hole did not exceed $L_{3-20\mathrm{keV}} \lesssim 3 \cdot 10^{33} (d/1kpc)^2$ ergs/s (where d is the distance to the black hole). Near the maximum of the background star amplification by the microlens (July 6, 1999), the upper limit on the X-ray flux corresponds to an X-ray luminosity $L_{3-20\mathrm{keV}} \lesssim 7 \cdot 10^{33} (d/1kpc)^2$ ergs/s.

Keywords: *RXTE/PCA, black holes, X-ray binaries, gravitational lensing, interstellar medium*

INTRODUCTION

The possibility of gravitational microlensing by stars in the Galaxy – an apparent increase in the optical brightness of the star, caused by the gravitational lensing by an object crossing the line of sight – has been discussed since 1970-1980th (see Paczynski 1996 for a review). However, because of the great technical problems in observing such events, the significant progress in this field was achieved only recently (MACHO and OGLE groups). So far, more than a thousand microlensing events have been discovered (see, e.g. Alcock et al., 2000, Wozniak et al., 2001).

During the crossing of the line of sight by a lensing object the brightness of the background star is changing in a specific way (see, e.g. Paczynski, 1986). The timescale of a microlensing event depends on the lens mass, the distances to the lens and to the background star, and the transverse velocity of the lens. Observational studies of the probability distribution of microlensing timescales show that the most frequent events occur on time scales of the order of 100 days, which indicates that the typical lens mass is of the order of a solar mass (see Paczynski, 1996; Alcock et al., 2000).

Recently, a more detailed investigation of the longest observed microlensing event OGLE-1999-BUL-32 (Mao et al., 2001) led to the conclusion that the lensing object was a black hole candidate. It was demonstrated that the mass of the lens $M \sim 4.4 M_\odot$ if the lens distance is d ∼6 kpc, and $M \sim 200 M_\odot$ if the lens distance is ∼500 pc (assuming that the background star resides in the bulge, $d_{star} \sim$ 7kpc). In any case, the lens mass appears to be beyond the mass limit for neutron stars. Therefore, the observations of the microlensing event OGLE-1999-BUL-32 strongly indicate the presence of a black hole in the direction of: $l = 2.46, b = -3.505$, or $\alpha = 18^h 05^m 05.35^s, \delta = -28^\circ 34' 42.5''$. The maximum amplification of the background star brightness occurred on July 6, 1999 (∼ TJD 11365).

In this Letter we derive an upper limit on the X-ray luminosity of the black hole OGLE-1999-BUL-32 using the data of RXTE/PCA scans over the Galactic Center region in 1999-2000.

OBSERVATIONS AND RESULTS

There are three scientific instruments aboard the Rossi X-ray Timing Explorer (RXTE) observatory: two coaligned spectrometers PCA (3–60 keV) and HEXTE (20-200 keV) with fields of view 1°, designed for detailed studies of X-ray sources, and an All Sky Monitor – ASM (1-12 keV), which allows one to follow their long term behavior. In Feb. 1999, a campaign of scans over the Galactic Center region with the PCA spectrometer was initiated. This instrument has a very large effective area (∼6500 cm^2), and the uncertainty in measuring the flux for sources detected in a single scan is of the order of 1–2 mCrabs. Therefore, it appeared that the data of PCA scan observations effectively complement the ASM monitoring results. Note that even in the scanning mode, PCA provides a sensitivity that is higher by an order of magnitude than that of ASM. This advantage in sensitivity becomes of particular importance if a given event is short so that ASM cannot provide us good statistics.

We analyzed approximately a hundred scanning PCA observations covering the period from Feb. 1999 to Mar.

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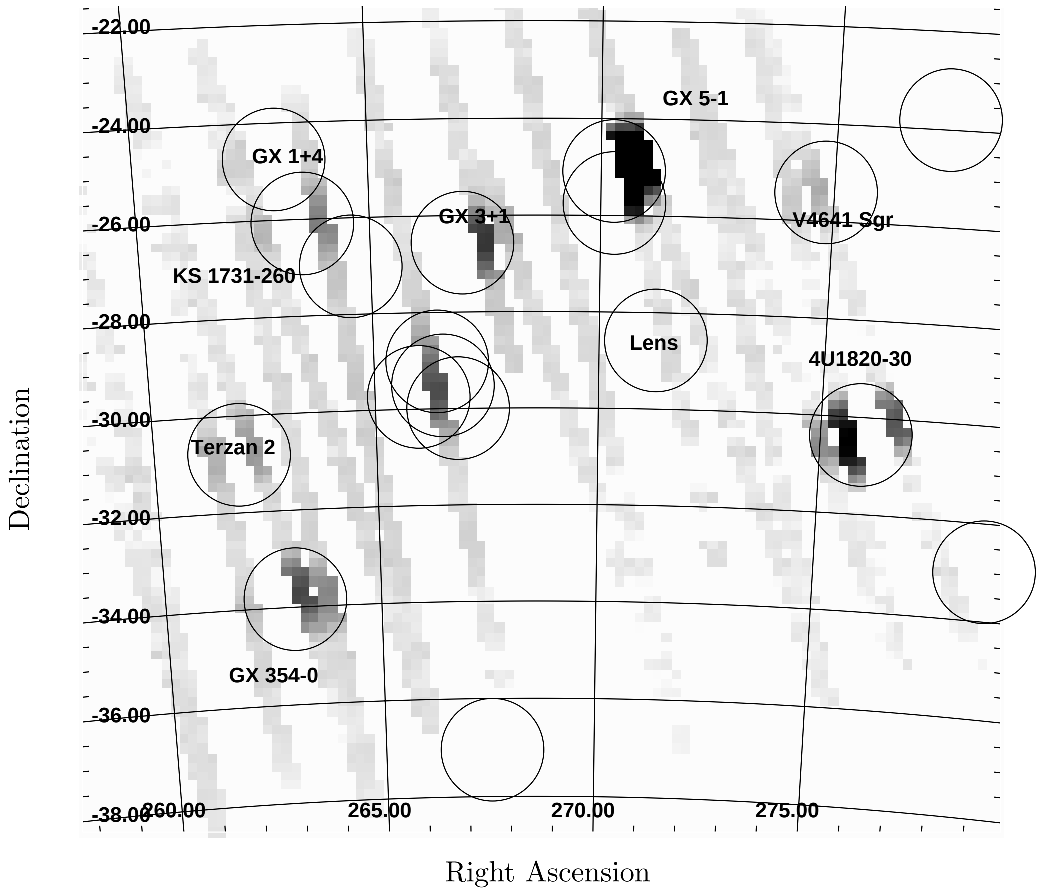

Fig. 1. Map of the Galactic Center region according to the PCA scan observations on July 7, 1999. Solid circles represent the regions of the bright sources "illumination" (see text).

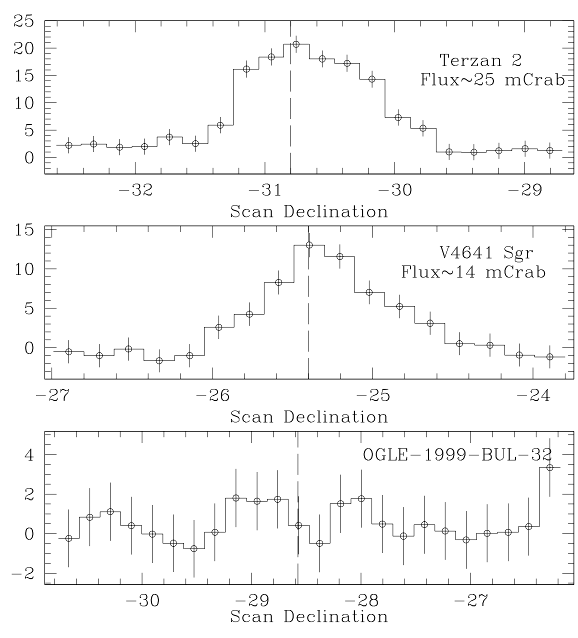

Fig. 2. Slices of the PCA scans over Terzan 2, V4641 Sgr and the microlens OGLE-1999-BUL-32 7 1999 .

2000. One of these scans was performed on July 7, 1999, i.e. very close to the maximum of the lensing amplification of the background star by OGLE-1999-BUL-32 .

The PCA data were analyzed with the help of standard tools of the LHEASOFT package. For the background estimation we used model $L7/240$.

Fig. 1 presents a map of the Galactic Center region, obtained from the PCA scan observations performed on July 7, 1999 (the effective energy band 3–20 keV). In constructing the map, the flux collected by the PCA over a 1 sec time interval was assigned to the celestial position corresponding to the center of the PCA field of view. This method of map construction causes 1° regions around bright objects to appear "illuminated" in accordance to the collimator radial response function. In Fig. 1 one can clearly see such "illumination" regions (they are indicated by solid circles) encircling well known bright objects GX5-1, 4U1820-30, GX3+1, GX354-0. Also apparent are comparably weak sources, including Terzan 2 and the accreting black hole in the high-mass binary system V4641 Sgr (the 3–20 keV X-ray flux from these sources was ∼25 mCrab and ∼14 mCrab correspondingly). In Fig. 2 we present the slices of PCA spectrometer scans over the positions of Terzan 2, V4641 Sgr and the microlens OGLE-1999-BUL-32 . It is seen that the flux from the position of OGLE-1999-BUL-32 in this observation did not exceed 1-2 mCrab.

In Fig. 3 we present a map of the Galactic Center region obtained using all available PCA scan observations during the period Feb.1999-Mar.2000. It should be noted here that despite the dramatic improvement in statistics (about 100 PCA scan observations were co-added), it proves impossible to improve significantly the upper limit on the source flux, because of the systematic uncertainties in the background subtraction and the influence of the Galactic diffuse emission. The upper limit on the X-ray flux from OGLE-1999-BUL-32 in this case $F_x \lesssim 1$ mCrab.

DISCUSSION

In the previous section we derived an upper limit on the 3–20 keV X-ray flux from OGLE-1999-BUL-32 of the order of $\lesssim 1$ mCrab (Feb.1999-Mar.2000), which corresponds to an X-ray luminosity $L_{3-20\mathrm{keV}} \lesssim 3 \cdot 10^{33}(\mathrm{d/1kpc})^2$ ergs/s, where d is the distance to the black hole.

This upper limit can be important for models considering the binary system harboring the black hole OGLE-1999-BUL-32 .

Observations of X-ray Novae – low mass binaries with black holes – have shown that there are thousands of recurrent transient X-ray sources in the Galaxy. These typically demonstrate X-ray activity only during several months every 50-70 years (see, e.g. Tanaka, Shibazaki, 1996, for a review). The discovery of an X-ray outburst of V4641 Sgr revealed that black holes, which are unobservable in X-rays at particular times, can also exist in high mass binary systems (Orosz et al. 2001). However, it is clear that a bright optical companion of the black hole OGLE-1999-BUL-32 would have been detected during the optical microlens observations. Therefore, the hypothesis of a high mass binary harboring the black hole OGLE-1999-BUL-32 appears very unlikely. However, the question of whether this black hole is in a low mass binary system still remains open given the possibility that the distance of the source is large ($d \gtrsim$3–4 kpc). In the case of a near ($d \sim$500 pc), massive ($M \sim 200 M_{\odot}$) black hole, the microlensing observations would have revealed the optical companion if it were more massive than $\gtrsim 0.2 M_{\odot}$. Therefore, we are coming to the conclusion that such a massive black hole should be single.

Observations have revealed a small amount of molecular hydrogen, $N_H L \sim 5 \cdot 10^{18}\mathrm{cm}^{-2}$, in the direction of the black hole OGLE-1999-BUL-32 (Dame et al., 1987). However, a much larger amount of neutral hydrogen is present in this direction – $N_H L \sim 3 \cdot 10^{21}$ cm^{-2} (Dickey, Lockman, 1990). This means that at energies lower than 0.5-1 keV the possible X-ray or UV source would be strongly absorbed.

According to McKee, Ostriker (1977), most of the volume of the Galaxy disk is filled by a rarefied gas with embedded molecular clouds and clouds of neutral hydrogen. The relatively low column density of molecular hydrogen in the direction of the source indicates that the probability of the black hole residing in a molecular cloud is rather low. However, the black hole might be in a neutral hydrogen cloud. In this case it could accrete matter from the interstellar medium at a rate sufficient for it to be detected in EUV or in X-rays.

Turbulent velocities and rotation of the gas in an interstellar cloud should lead to the formation of a disk during the accretion onto the compact object. If the innermost regions of the accretion flow are not dominated by advection (not an ADAF-like flow), then the emission of the accretion disk can be described by the multicolor disk model (Shakura, Sunyaev, 1973). If the accretion rate is small, which is presumably true in our case, the maximal temperature of the accretion disk does not exceed 0.5 keV, hence most of the energy is radiated outside our energy band (3–20 keV). This makes it very difficult to place an upper limit on the bolometric luminosity of the black hole, using our measurements in 3–20 keV energy band. A more accurate estimate could be made if CHANDRA of XMM-NEWTON data were available (the effective energy band is $\sim$0.1-10 keV).

It was shown in the previous section that one of the scanning PCA observations was performed 1 day after the maximum of the background star brightness amplification took place (cf. with the characteristic time of the microlensing event $\sim$640 days). The upper limit on the X-ray flux from the lens/background star during this observation is $F_x \lesssim 2.5$ mCrab (2σ). Taking into account that the background star amplification was then $\sim$12, we can put an upper limit on the X-ray luminosity of this background star (assuming that it is located in the Galactic bulge with $d \sim$ 7kpc): $L_x \lesssim 2 \cdot 10^{34}$ ergs/s. This upper limit is not very stringent, as it exceeds the luminosity of the most powerful X-ray flares of the Sun.

The fact of detection of a massive object that is very faint in optics and X-rays tells us that black holes in the interstellar medium are not exotic phenomena. It is obvious that some of them can from time to time pass through a dense molecular clouds and clouds of interstellar gas. When such an event takes place, these objects can start emit X-rays and can be detectable at the level of sensitivity of the RXTE observatory.

Unfortunately, a source with a luminosity $L_x > 10^{37}$ ergs/s can heat the surrounding medium to high temperatures in quite a short period of time, and that will cause an outflow of matter. This, in turn, will lead to a turn-off of the accretion even if the original density of the cloud was high enough (Sunyaev, 1978).

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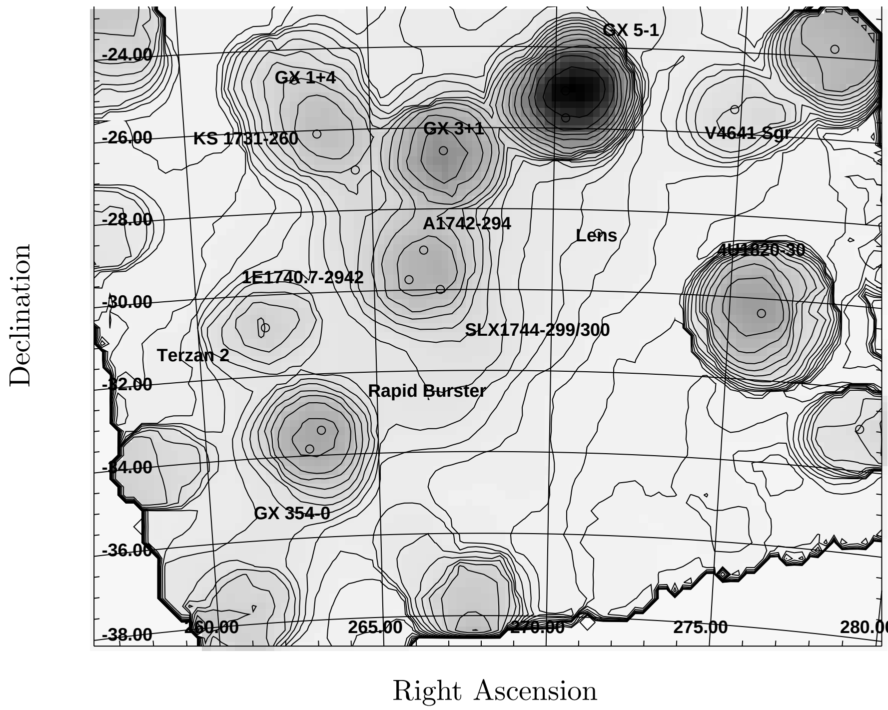

Fig. 3. Map of the Galactic Center region by PCA scan observations, averaged over Feb.1999-Mar.2000.

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